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Relationship of Meteorology to Summer Ozone in Southern Louisiana

Radian Corp, Austin, TX

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RELATIONSHIP OF METEOROLOGY TO SUMMER OZONE IN SOUTHERN LOUISIANA

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16. ABSTRACT

Continuous ozone data obtained at nine sites across southern Louisiana showed that the ozone levels frequently exceeded the federal standard of 80 parts per billion during the three month study period. The days with ozone over the standard were generally characterized as having light winds, abundant sunshine, and high temperatures. Intermittent periods of region wide low ozone were primarily associated with widespread thunderstorm activity. The cold fronts which passed through southern Louisiana during the study period were conducive to nighttime ozone levels which were higher than nighttime levels typically observed during the study period.

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EXECUTIVE SUMMARY

Continuous ozone and meteorological data were obtained at nine sites across southern Louisiana during the period from mid-July through mid-October 1976. Ozone levels were generally high during the three-month period; the federal standard of 80 parts per billion was exceeded many times at each of the sites. Although ozone levels were generally high during the period, there were intermittent periods of regionwide low ozone levels.

An investigation into the relationships of synoptic, regional, and local meteorology to ozone levels revealed that high ozone levels during the monitoring period generally occurred on sunny days with light winds and high temperatures. The intermittent periods of regionwide low ozone levels were primarily associated with widespread thunderstorm activity across southern Louisiana. The cold fronts which passed through southern Louisiana during the study period were conducive to nighttime ozone levels which were higher than nighttime levels typically observed during the study period.

No clear relationship between ozone levels and dew points was observed. Furthermore, no clear relationship between ozone levels and the curvature of pressure systems was observed; apparently, other meteorological conditions that occur with a given curvature are more important than the curvature itself, at least during the summer and early fall.

The relationships between meteorology and ozone levels are complex, due to the interrelationships of individual meteorological parameters and the superimposed effects of ozone precursors and scavengers.

1.0 INTRODUCTION

Past studies have shown that meteorology plays an important role in the generation, transport, and destruction of ozone. The purpose of this paper is to relate three months of surface ozone data from southern Louisiana to synoptic, regional, and local meteorological conditions which existed during the ozone monitoring period.

2.0 DESCRIPTION OF THE AIR MONITORING PROGRAM

Under contract with the Environmental Protection Agency, Radian Corporation conducted an air monitoring program at nine locations in southern Louisiana (see Figure 2-1) during the period from July 17, 1976 to October 17, 1976. Ozone was measured at each monitoring trailer by the chemiluminescent method. In addition to ozone, each of the nine sites continuously monitored nitrogen oxides and sulfur dioxide. Total suspended particulate concentrations were determined for each twenty-four hour period. Various meteorological parameters were also measured at the monitoring sites (see Table 2-1).

A detailed description of the monitoring systems, including air quality and meteorological instrumentation types and specifications, is contained in the Final Report - "A Study of Ozone Concentrations in Southern Louisiana."

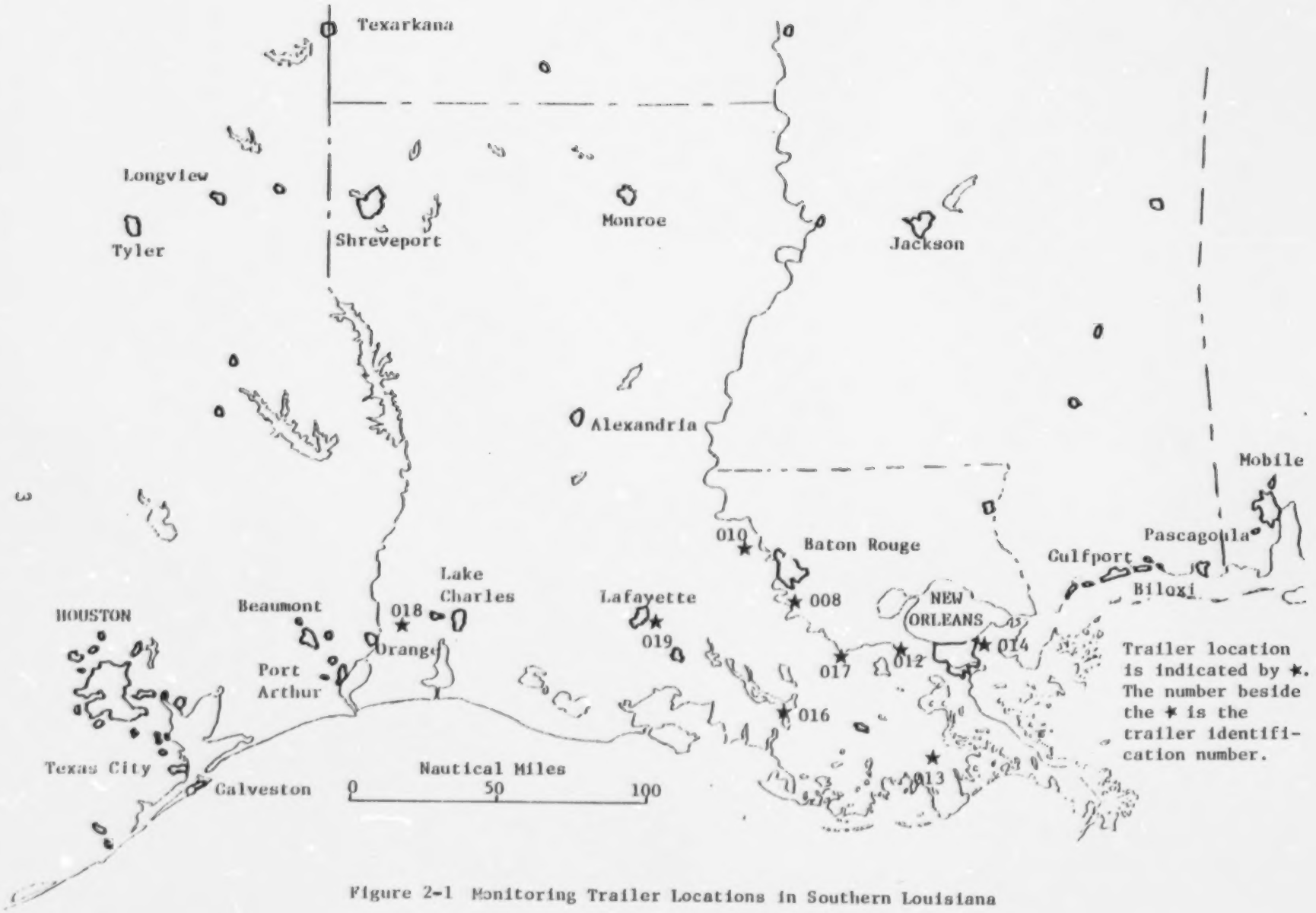

Figure 2-1 Monitoring Trailer Locations in Southern Louisiana

TABLE 2-1. Meteorological Parameters Measured at the Southern Louisiana Monitoring Sites

Trailer \ Meteorological Parameter	Temperature	Wind Speed	Wind Direction	Relative Humidity	Precipitation	Solar Radiation
008	x	x	x	x		
010	x	x	x	x (July, August)		x (August, September, October)
012	x	x	x	x		x (August, September, October)
013	x	x	x	x		
014	x	x	x	x	x	x (July)
016	x	x	x	x	x (July)	
017	x	x	x	x	x	x (July)
018	x	x	x	x		
019	x	x	x	x	x	x

3.0 CLASSIFICATION OF MONITORING SITES

Each of the nine monitoring sites in southern Louisiana is near significant sources of possible ozone precursors and scavengers, as Table 3-1 indicates. However, none of the sites are located within highly developed, densely populated urban complexes. Therefore, the nine monitoring sites can be classified as neither truly rural nor truly urban.

TABLE 3-1. Sources of Possible Ozone Precursors and Scavengers Near the Southern Louisiana Monitoring Sites

Trailer	Sources of Possible Ozone Precursors and Scavengers
008	1. Baton Rouge to the north 2. Power plants and chemical plants to the northwest and southwest 3. Oil field to the east 4. Transportation on Louisiana Highway 30
010	1. Large industrial complex to the southeast along Mississippi River at Baton Rouge (oil refineries, metals industries, petrochemical complexes) 2. Baton Rouge southeast 3. Transportation on Louisiana Highway 413
012	1. Surrounded by refineries, chemical plants, power plants 2. Heavy barge and shipping traffic along Mississippi River 3. New Orleans to the east
013	1. Barge traffic on LaFourche Bayou 2. Transportation on Louisiana Highways 1 and 308 3. Oil and gas fields in area 4. New Orleans to the north
014	1. Industries along surrounding waterways 2. Heavy shipping traffic on Intracoastal Waterway and Mississippi River Outlet Canal 3. New Orleans to west
016	1. Barge and shipping traffic along bayous and Atchafalaya River 2. Industry in area 3. Oil and gas fields in area 4. Morgan City to the north
017	1. Transportation Louisiana Highway 18 2. Refineries and petrochemical plants along Mississippi River 3. Heavy barge and shipping traffic on Mississippi River 4. Oil and gas fields to the west 5. New Orleans to the east

TABLE 3-1. Sources of Possible Ozone Precursors and Scavengers Near the Southern Louisiana Monitoring Sites

Continued

Trailer	Sources of Possible Ozone Precursors and Scavengers
018	1. Large refining and petrochemical complex southwest at Orange, Texas 2. Refineries and petrochemical plants to the east at Sulphur and Lake Charles 3. Oil and gas fields surrounding Vinton
019	1. Heavy automobile and airplane traffic at Lafayette Regional Airport 2. Lafayette to the west 3. A few oil and gas fields in area

4.0 OZONE DATA PRESENTATION

A computer plot of Class I ozone concentrations (in parts per billion) at each monitoring site for the three-month period is presented in Figure 4-1. Class I ozone data are those data bracketed with a multi-point calibration and subsequent quality assurance audits, with the audit results being within ±15 percent of the control-sample value. In Figure 4-1, the trailers are listed from top to bottom in the order of their west to east progression across southern Louisiana. The scale is zero to 200 parts per billion, and the dashed line is the federal standard for ozone, 80 parts per billion. The computer plot was created for ease in detecting trends in ozone concentrations, on both a temporal and spatial basis.

Figure 4-1 shows that, during the monitoring period, the ambient air quality standard of 80 parts per billion was frequently exceeded at all sites. The type of diurnal variation which generally occurred (very low nighttime ozone levels and high daytime values) is similar to the diurnal variation shown by past studies to be typical of urban/industrial areas. Sites in truly rural areas, where there are few sources of ozone precursors and scavengers, tend to exhibit much less diurnal variation. A study of an ozone episode in Texas in 1975 by Hathorn and Walker[1] is one such study which showed large diurnal variations in urban/industrial areas and much smaller diurnal variations in areas where emissions were insignificant.

Figure 4-1 shows that there were definite systemwide trends in ozone levels. For example, there were several periods of systemwide low ozone levels. Site-to-site variations in ozone levels were also evident.

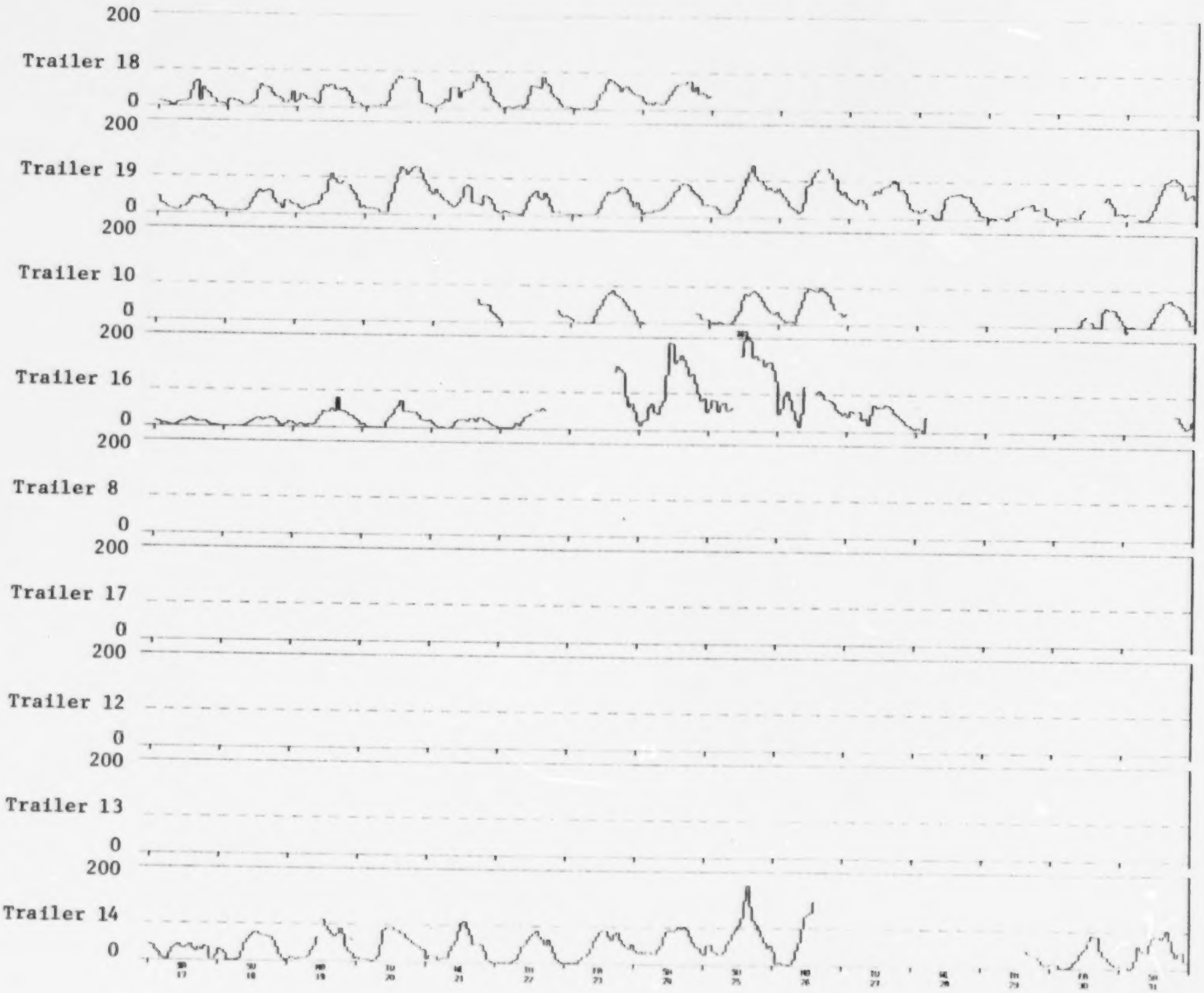

Figure 4-1. Ozone Concentrations (ppb) at the Trailer Monitoring Sites
July 17-31, 1976

(Continued)

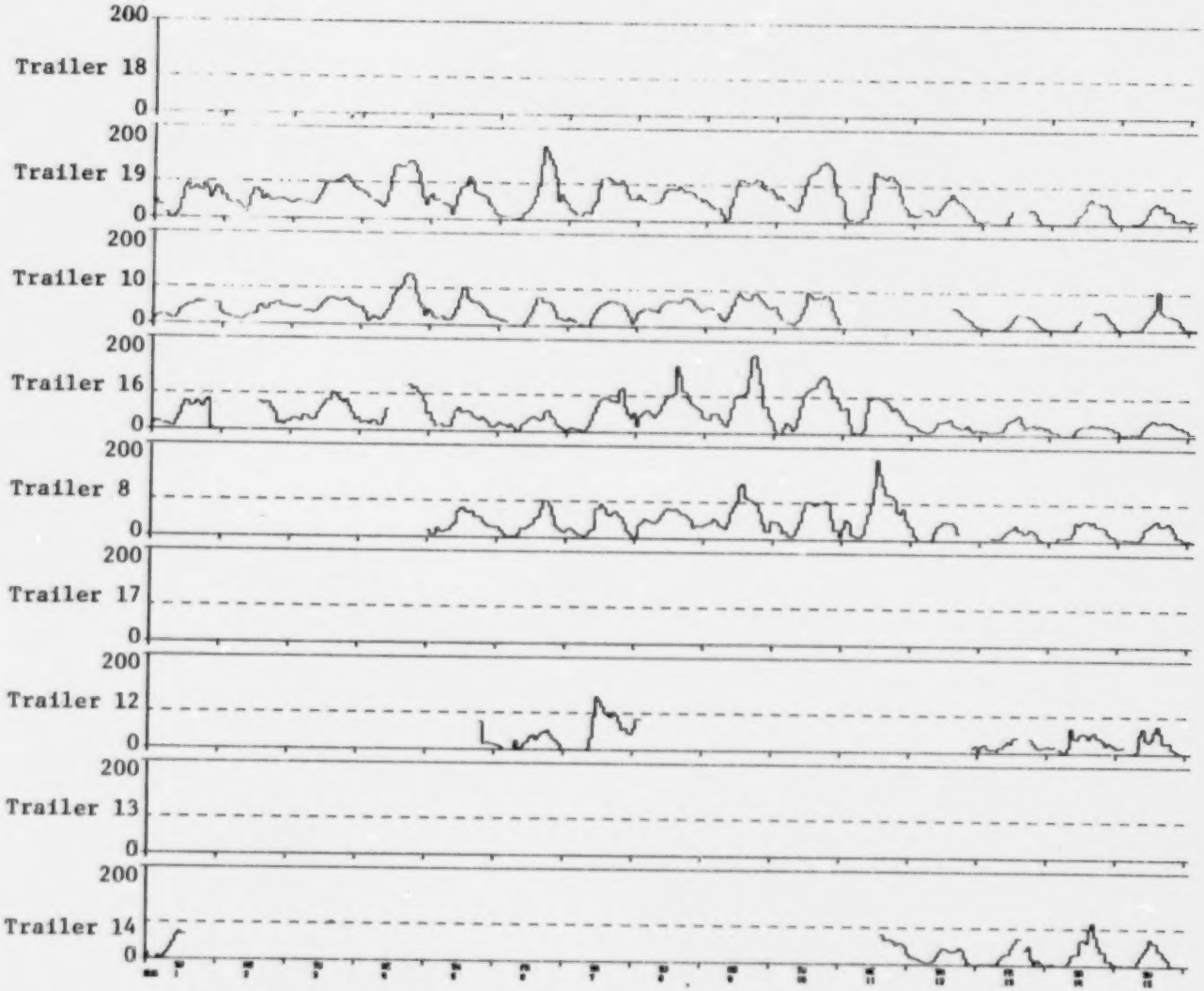

Figure 4-1. Ozone Concentrations (ppb) at the Trailer Monitoring Sites
August 1-15, 1976

(Continued)

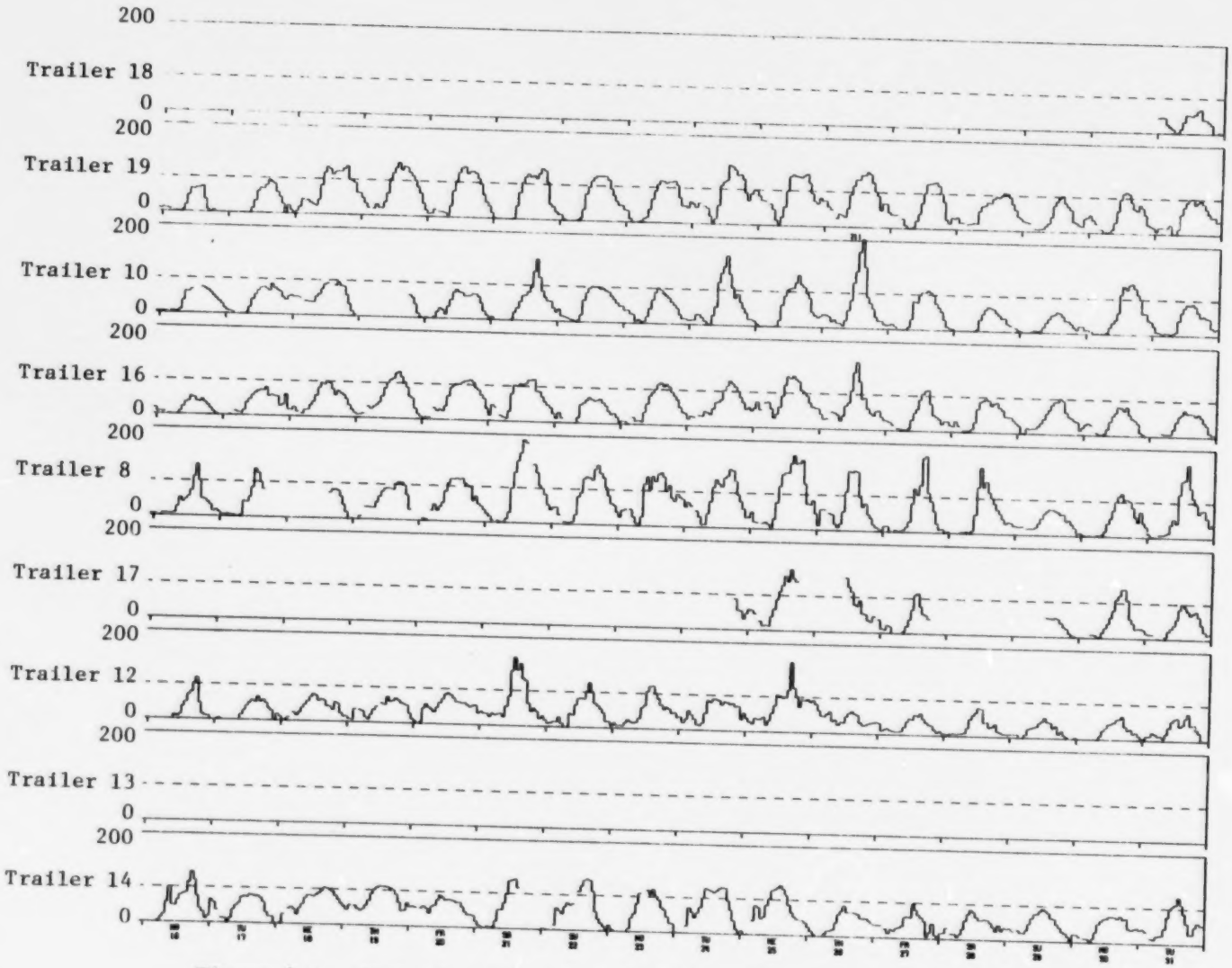

Figure 4-1. Ozone Concentrations (ppb) at the Trailer Monitoring Sites
August 16-31, 1976

(Continued)

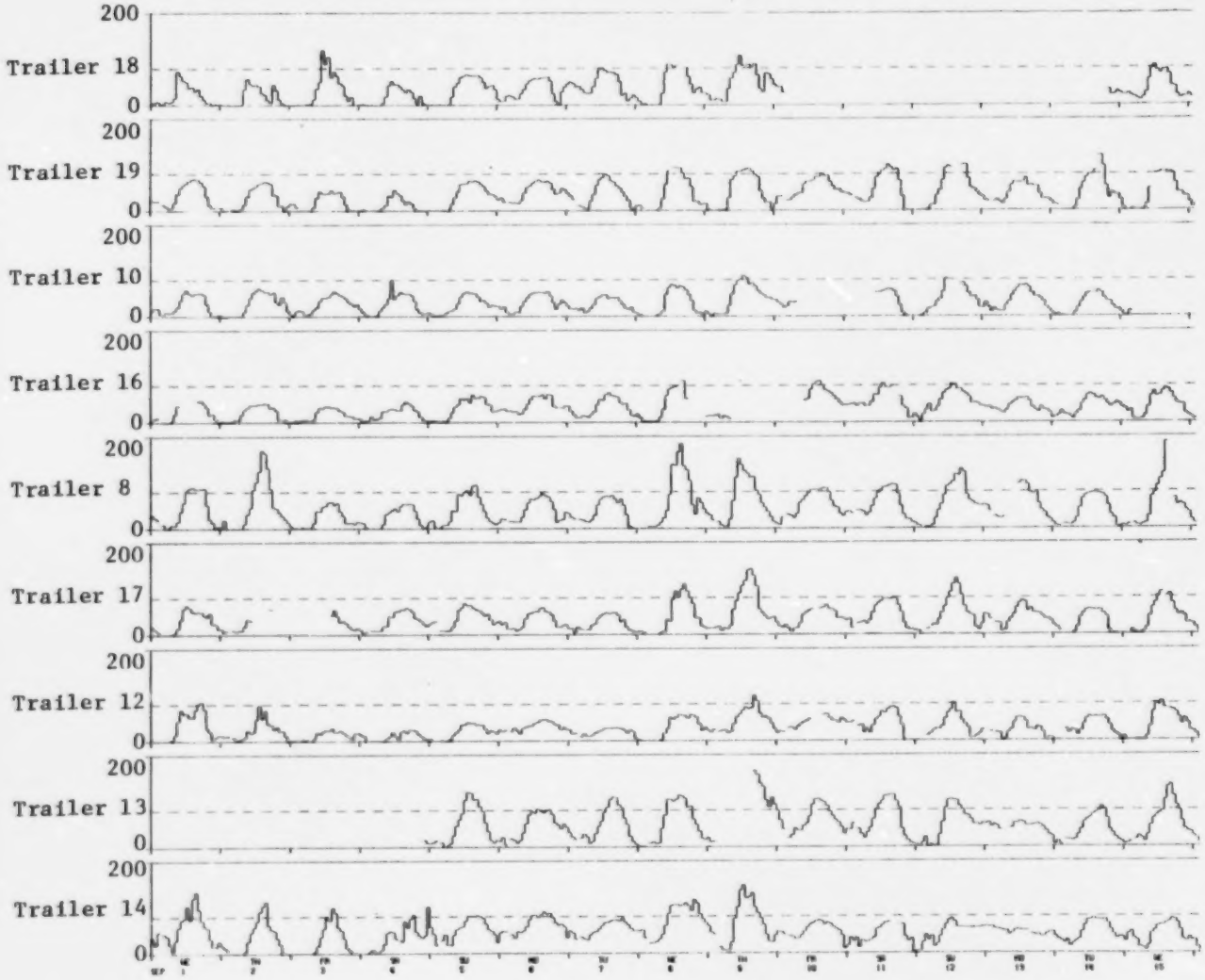

Figure 4-1. Ozone Concentrations (ppb) at the Trailer Monitoring Sites
September 1-15, 1976

(Continued)

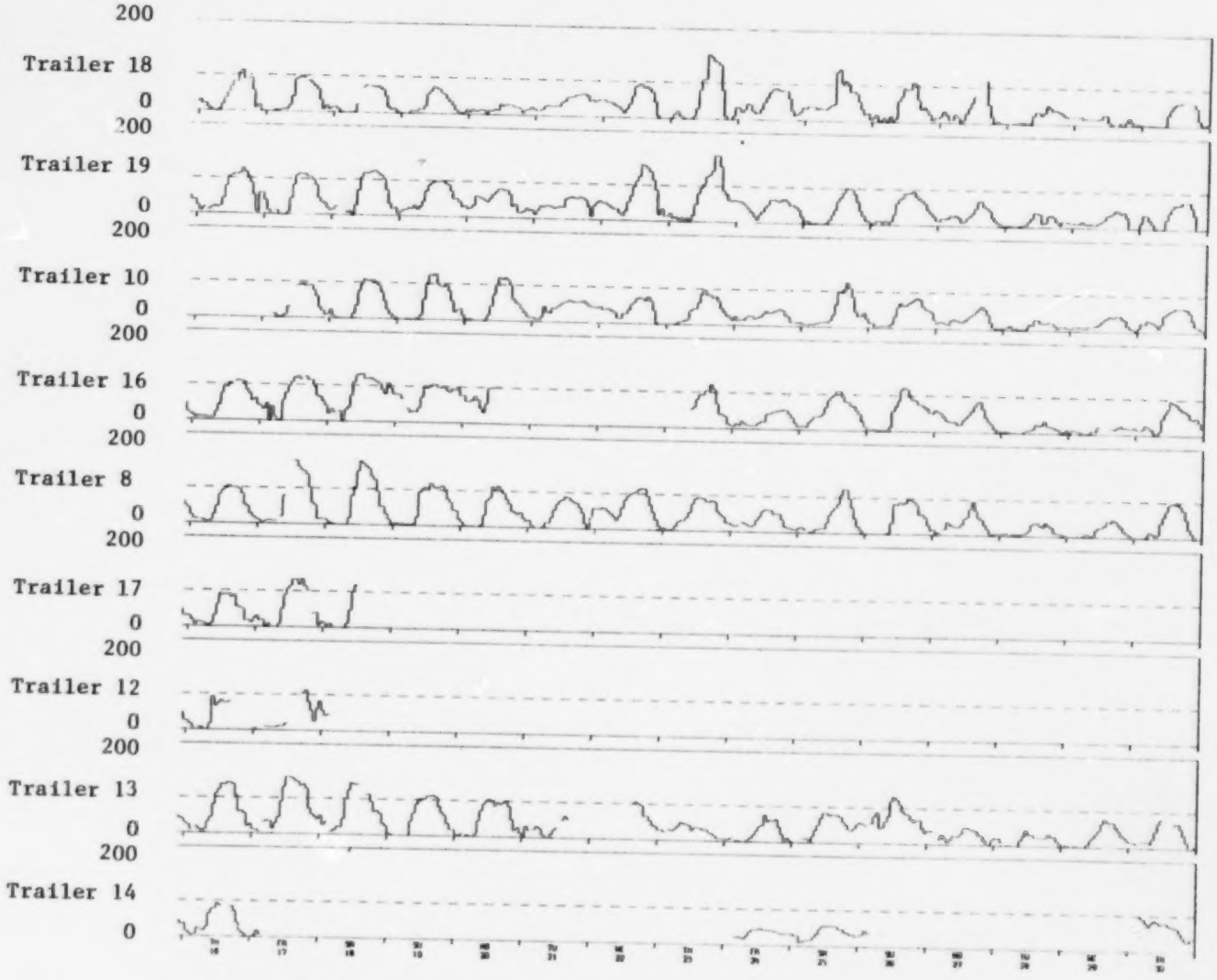

Figure 4-1. Ozone Concentrations (ppb) at the Trailer Monitoring Sites
September 16-30, 1976

(Continued)

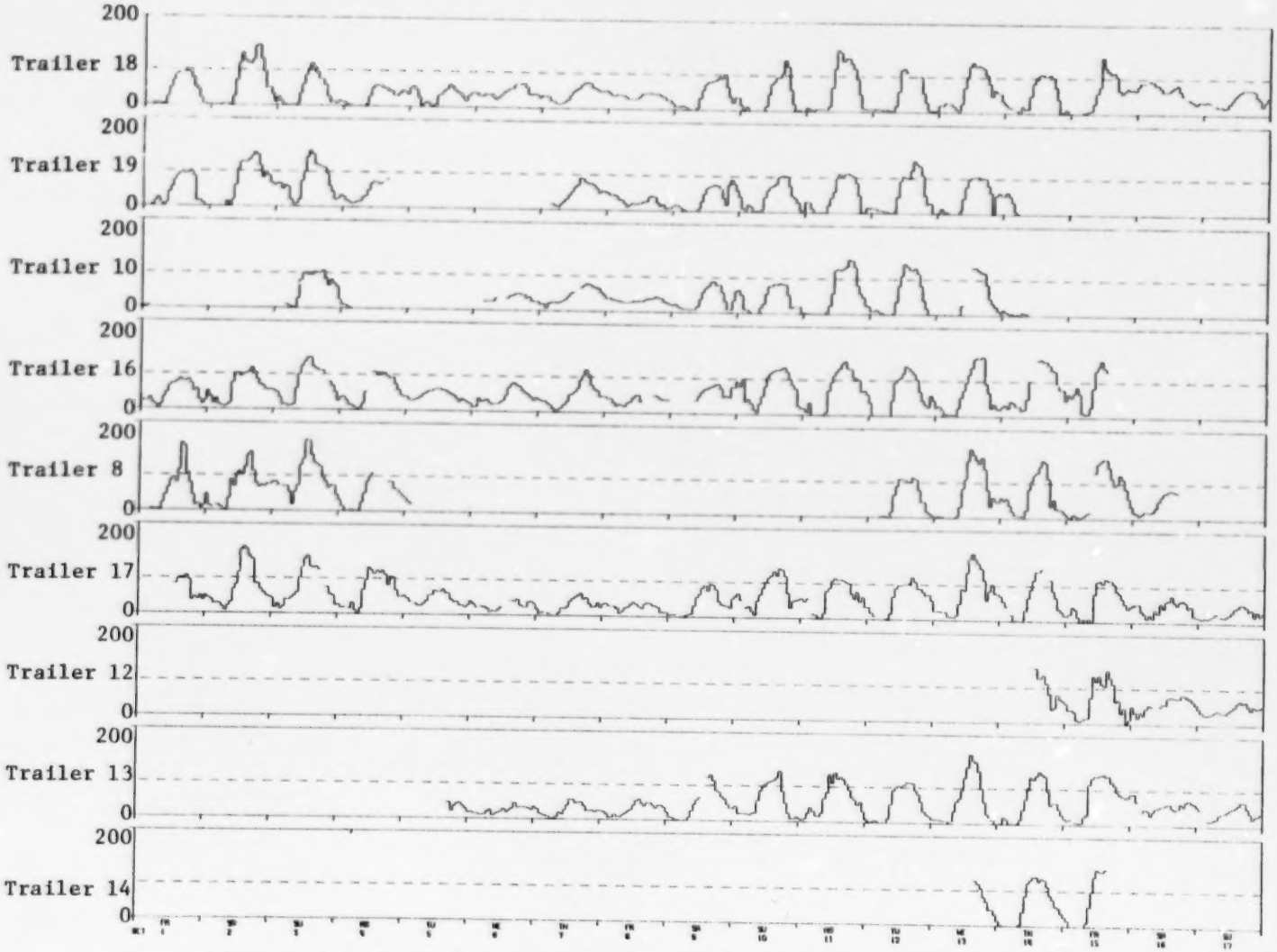

Figure 4-1. Ozone Concentrations (ppb) at the Trailer Monitoring Sites
October 1-17, 1976

5.0 SYNOPSIS OF METEOROLOGICAL CONDITIONS IN SOUTHERN LOUISIANA DURING THE THREE-MONTH MONITORING PERIOD

Sky cover, precipitation, persistent winds, and frontal passages during the monitoring period are presented on a daily basis in Table 5-1. The data are separated according to three regions (the western, central, and eastern portions of southern Louisiana) due to the variability in meteorological conditions which may occur across southern Louisiana. Trailer 018 is the only trailer located in the western section, while Trailers 019, 010, 016, 008, and 017 are considered to be located in the central section. The eastern section includes Trailers 012, 013, and 014.

Except for frontal passages, the meteorological data presented in Table 5-1 are limited to daytime. Data presented in the table were obtained from both National Weather Service records and from the monitoring trailers.

In the table, sky cover is designated as clear, partly cloudy, or cloudy. Sky cover is not given if thunderstorms occurred, as cloudiness is usually quite variable on days when thunderstorms occur.

Precipitation is noted as showers, thunderstorms, drizzle, etc. Summertime precipitation is almost exclusively recorded in thunderstorms in southern Louisiana.

Persistent winds were recorded if winds blew from a reasonably persistent direction during the day. By "reasonably persistent" it is meant that winds during the day blew from directions which fell within a sector of ninety degrees. For example, winds which blew within the sector from northeast to southeast were considered reasonably persistent. Wind speeds

TABLE 5-1. Sky Cover, Precipitation, Persistent Winds, and Fronts in Southern Louisiana

July 17 - October 17, 1976

	West				Central				East			
Date	Sky Cover	Precipitation	Persistent Winds (mph)	Fronts	Sky Cover	Precipitation	Persistent Winds (mph)	Fronts	Sky Cover	Precipitation	Persistent Winds (mph)	Fronts
July												
17		Thunderstorms				Thunderstorms				Thunderstorms		
18		Thunderstorms			Ptly Cldy					Thunderstorms		
19	Ptly Cldy				Ptly Cldy					Thunderstorms		
20	Ptly Cldy		Lt. Easterly			Thunderstorms				Thunderstorms		
21		Thunderstorms				Thunderstorms				Thunderstorms		
22		Thunderstorms				Thunderstorms				Thunderstorms		
23		Thunderstorms				Thunderstorms				Thunderstorms		
24		Thunderstorms				Thunderstorms			Ptly Cldy			
25	Ptly Cldy					Thunderstorms				Thunderstorms		
26	Ptly Cldy		SSE to SSW 5-10			Thunderstorms				Thunderstorms		
27	Ptly Cldy		SW 4-8		Ptly Cldy		SW 4-8		Ptly Cldy		SW 4-8	
28		Thunderstorms			Ptly Cldy		SW 5-10			Thunderstorms		
29		Thunderstorms				Thunderstorms				Thunderstorms		
30	Ptly Cldy		W to SW 5-10		Ptly Cldy		W to SW 5-10			Thunderstorms		
31	Ptly Cldy		WNW to WSW 5-10		Ptly Cldy		WNW to WSW 5-10			Thunderstorms		
August												
1	Ptly Cldy		NW to W 5-10		Ptly Cldy		NW to W 5-10			Thunderstorms		
2		Showers, thunderstorms, preceeding cool front	NW to NE 5-10 behind front	Cool front		Showers, thunderstorms, preceeding cool front	NW to NE 5-10 behind front	Cool front		Showers, thunderstorms, preceeding cool front	NW to NE 5-10 behind front	Cool front
3	Clr by mid-day		N to NE 8-14		Clr by mid-day		N to NE 8-14		Clr by mid-day		N to NE 8-14	
4	Ptly Cldy		Lt NE to SE		Ptly Cldy		Lt NE to SE			Showers		
5		Thunderstorms				Thunderstorms				Thunderstorms		
6	Ptly Cldy		W 6-12		Ptly Cldy		W 6-12			Thunderstorms		
7	Ptly Cldy		W to NW 6-12	Cool front		Thunderstorms		Cool front		Thunderstorms		Cool front
8	Clr		NW to NE 6-12		Clr		NW to NE 6-12		Clr		NW to NE 6-12	
9	Clr		NE to N 5-10		Clr		NE to N 5-10		Clr		NE to N 5-10	
10	Clr				Clr			Clr				
11	Ptly Cldy				Ptly Cldy				Ptly Cldy			
12		Thunderstorms				Thunderstorms				Thunderstorms		
13		Thunderstorms				Thunderstorms				Thunderstorms		
14		Thunderstorms				Thunderstorms				Thunderstorms		
15		Thunderstorms				Thunderstorms				Thunderstorms		
16		Thunderstorms				Thunderstorms				Thunderstorms		
17		Thunderstorms					SW to NW 4-8			Thunderstorms		
18	Ptly Cldy		ENE to ESE 8-15		Ptly Cldy		ENE to ESE 8-15		Ptly Cldy		ENE to ESE 8-15	
19	Ptly Cldy		ENE to ESE 8-18		Ptly Cldy		ENE to ESE 8-18		Ptly Cldy		ENE to ESE 8-18	
20	Ptly Cldy		ENE to ESE 5-10		Ptly Cldy		ENE to ESE 5-10		Ptly Cldy		ENE to ESE 5-10	
21	Ptly Cldy				Ptly Cldy					Thunderstorms		
22	Ptly Cldy				Ptly Cldy				Ptly Cldy			
23		Thunderstorms			Ptly Cldy					Thunderstorms		
24	Ptly Cldy					Thunderstorms				Thunderstorms		
25	Ptly Cldy				Ptly Cldy				Ptly Cldy			

Continued

TABLE 5-1. Sky Cover, Precipitation, Persistent Winds, and Fronts in Southern Louisiana

July 17 - October 17, 1976

	West				Central				East			
Date	Sky Cover	Precipitation	Persistent Winds (mph)	Fronts	Sky Cover	Precipitation	Persistent Winds (mph)	Fronts	Sky Cover	Precipitation	Persistent Winds (mph)	Fronts
August												
26	Ptly Cldy					Thunderstorms				Thunderstorms		
27	Ptly Cldy		S 5-10			Thunderstorms				Thunderstorms		
28		Thunderstorms				Thunderstorms				Thunderstorms		
29	Ptly Cldy		ENE 5-10			Thunderstorms				Thunderstorms		
30	Ptly Cldy					Thunderstorms				Thunderstorms		
31	Ptly Cldy to Cldy		SE to SW 5-10	Stationary front		Thunderstorms		Stationary front		Thunderstorms		Stationary front
Sept.												
1	Ptly Cldy		SE to SW 5-10	Stationary front	Ptly Cldy		SE to SW 5-10	Stationary front		Thunderstorms		Stationary front
2	Ptly Cldy					Thunderstorms				Thunderstorms		
3		Thunderstorms				Thunderstorms				Thunderstorms		
4		Thunderstorms				Thunderstorms				Thunderstorms		
5	Ptly Cldy		NNW to NE 5-10		Ptly Cldy		NNW to NE 5-10		Ptly Cldy		NNW to NE 5-10	
6	Ptly Cldy		ENE 6-12		Ptly Cldy		ENE 6-12			Thunderstorms		
7	Ptly Cldy				Ptly Cldy					Thunderstorms		
8		Thunderstorms			Ptly Cldy					Thunderstorms		
9		Thunderstorms late afternoon		Cool front		Thunderstorms late afternoon				Thunderstorms late afternoon		
10	Ptly Cldy to Cldy		NW to N 10-15		Ptly Cldy to Cldy		NW to N 10-15	Cool front	Ptly Cldy to Cldy		NW to N 10-15	Cool front
11	Ptly Cldy				Ptly Cldy				Ptly Cldy			
12	Ptly Cldy		ENE to SE 8-14		Ptly Cldy		ENE to SE 8-14		Ptly Cldy		ENE to SE 8-14 Gusty	
13		Thunderstorms				Thunderstorms				Thunderstorms		
14		Thunderstorms				Thunderstorms			Ptly Cldy		N to E 5-10	
15		Thunderstorms				Thunderstorms			Ptly Cldy		NW to NE 5-10	
16	Ptly Cldy				Ptly Cldy				Ptly Cldy			
17	Ptly Cldy		SE to SW 5-10		Ptly Cldy		SE to SW 5-10		Ptly Cldy		Light North	
18	Ptly Cldy		SE to SW 5-10		Ptly Cldy		SE to SW 5-10		Ptly Cldy		Light North	
19	Ptly Cldy		SE to SW 5-10		Ptly Cldy		SE to SW 5-10		Ptly Cldy		Light North	
20		Showers, thunderstorms				Showers, thunderstorms			Ptly Cldy		Light North	
21	Ptly Cldy		N to NE 6-12	Cool front	Ptly Cldy		N to NE 6-12	Cool front	Cloudy		N to NE 6-12	Cool front
22	Ptly Cldy		NE 6-12		Ptly Cldy		NE 6-12		Ptly Cldy		NE 6-12	
23	Ptly Cldy		Lt N		Ptly Cldy		NE 5-10			Thunderstorms		
24	Ptly Cldy		NE 6-12			Thunderstorms early				Thunderstorms		
25	Ptly Cldy				Ptly Cldy				Ptly Cldy		Lt North	
26	Ptly Cldy		SW to WSW 5-10		Ptly Cldy		SW to WSW 5-10		Ptly Cldy		SW to WSW 5-10	

TABLE 5-1. Sky Cover, Precipitation, Persistent Winds, and Fronts in Southern Louisiana

July 17 - October 17, 1976

Continued

Date	West				Central				East			
	Sky Cover	Precipitation	Persistent Winds (mph)	Fronts	Sky Cover	Precipitation	Persistent Winds (mph)	Fronts	Sky Cover	Precipitation	Persistent Winds (mph)	Fronts
Sept.												
27		Thunderstorms early				Thunderstorms early				Thunderstorms early		
28		Thunderstorms		Cool front		Thunderstorms		Cool front		Thunderstorms		Cool front
29	Cloudy		NW to N 6-12		Cloudy		NW to N 6-12		Cloudy		NW to N 6-12	
30	Clear		NW to N 8-12 Gusty		Clear		NW to N 8-12 Gusty		Clear		NW to N 8-12 Gusty	
Oct.												
1	Clear				Clear				Clear			
2	Ptly Cldy				Ptly Cldy				Ptly Cldy			
3	Ptly Cldy		SE to SW 5-10		Ptly Cldy		SE to SW 5-10		Ptly Cldy			
4	Ptly Cldy		SE to S 8-14		Ptly Cldy		SE to S 8-14		Ptly Cldy		SE to S 8-14	
5	Cloudy		S 8-14 ahead of front.W to NW 5-10 behind front	Cool front		Showers	S 8-14 ahead of front.W to NW 5-10 behind front	Cool front	Cloudy		S 8-14 ahead of front.W to NW 5-10 behind front	Cool front
6	Clr from W		N 8-16		Clr from W		N 8-16		Cloudy		N 8-16	
7	Clear		NW to NNE 5-10		Clear		NW to NNE 5-10			Drizzle	NW to NNE 5-10	
8	Cloudy		NW 8-14		Cloudy		NW 8-14			Light rain, drizzle	NW 8-14	
9	Ptly Cldy		W 5-10		Ptly Cldy		W 5-10		Ptly Cldy		W 5-10	
10	Ptly Cldy				Ptly Cldy				Ptly Cldy			
11	Clear				Clear				Clear			
12	Ptly Cldy		NE to SE 5-10		Ptly Cldy		NE to SE 5-10		Ptly Cldy		NE to SE 5-10	
13	Ptly Cldy				Ptly Cldy				Ptly Cldy			
14	Ptly Cldy				Ptly Cldy				Ptly Cldy			
15	Cldy to Ptly Cldy		E to S 5-10		Ptly Cldy		E to S 5-10		Ptly Cldy			
16		Showers, thundershowers		Cool front		Showers, thundershowers		Cool front		Showers, thundershowers		Cool front
17	Clear		N 10-20		Clear		N 10-20		Clear		N 10-20	

August

Although temperatures during August were generally near normal over southern Louisiana, rainfall was generally much below normal. Unusually strong high pressure ridges extending into Louisiana from the northern and northeastern United States dominated the weather in southern Louisiana during a high percentage of the days during the month. This strong ridging resulted in a higher than normal frequency of winds of a northerly component, especially northeasterly winds. Therefore, Gulf moisture was not available for the formation of thunderstorms on as many days as during a typical August. The only extended period of thunderstorm activity over all of southern Louisiana during August was the period from August 12th through 16th. On several other days, thunderstorms were scattered over portions of southern Louisiana. Two continental polar frontal passages occurred in southern Louisiana during August (August 2nd and 7th). A stationary front stretched across the region on August 31st.

September

As in August, temperatures across southern Louisiana were near normal during September, while rainfall was below normal. The orientation of pressure systems during the month was fairly typical, with a ridge of high pressure extending into the region from the eastern United States on a number of days during the month. Therefore, winds from the northeast to east were common during September. Northwesterly winds were more common than during the summer months, as a result of more frequent frontal passages. Maritime polar frontal passages occurred on September 10th and 21st, while a continental polar front passed through southern Louisiana on September 28th. A stationary

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front stretched across the region on September 1st. Although thunderstorms were scattered over portions of the region on about half of the days during the month, the only days on which thunderstorms occurred across all of southern Louisiana were September 3rd, 4th, 9th, 12th, 13th, and 27th. The number of thunderstorms which occurred during September was not unusually low, but total rainfalls for the month were below normal probably due to the lack of tropical storms which are normally expected to influence the region during September.

October

Temperatures varied markedly during the period from October 1st through October 17th. On several days, temperatures were very much below normal, while on some days, temperatures were above normal. The variability in temperatures was the result of two strong maritime polar cold fronts which passed through the region on October 5th and 16th. The eastward progression of major weather systems during the period from October 1st through 17th resulted in a high frequency of winds of a northerly component as well as of a southerly component. Showers and thundershowers occurred over all of southern Louisiana on only one day - October 16th. Precipitation was scattered over isolated portions of the region on October 5th, 7th, and 8th.

6.0 RELATIONSHIP OF OZONE TO METEOROLOGY

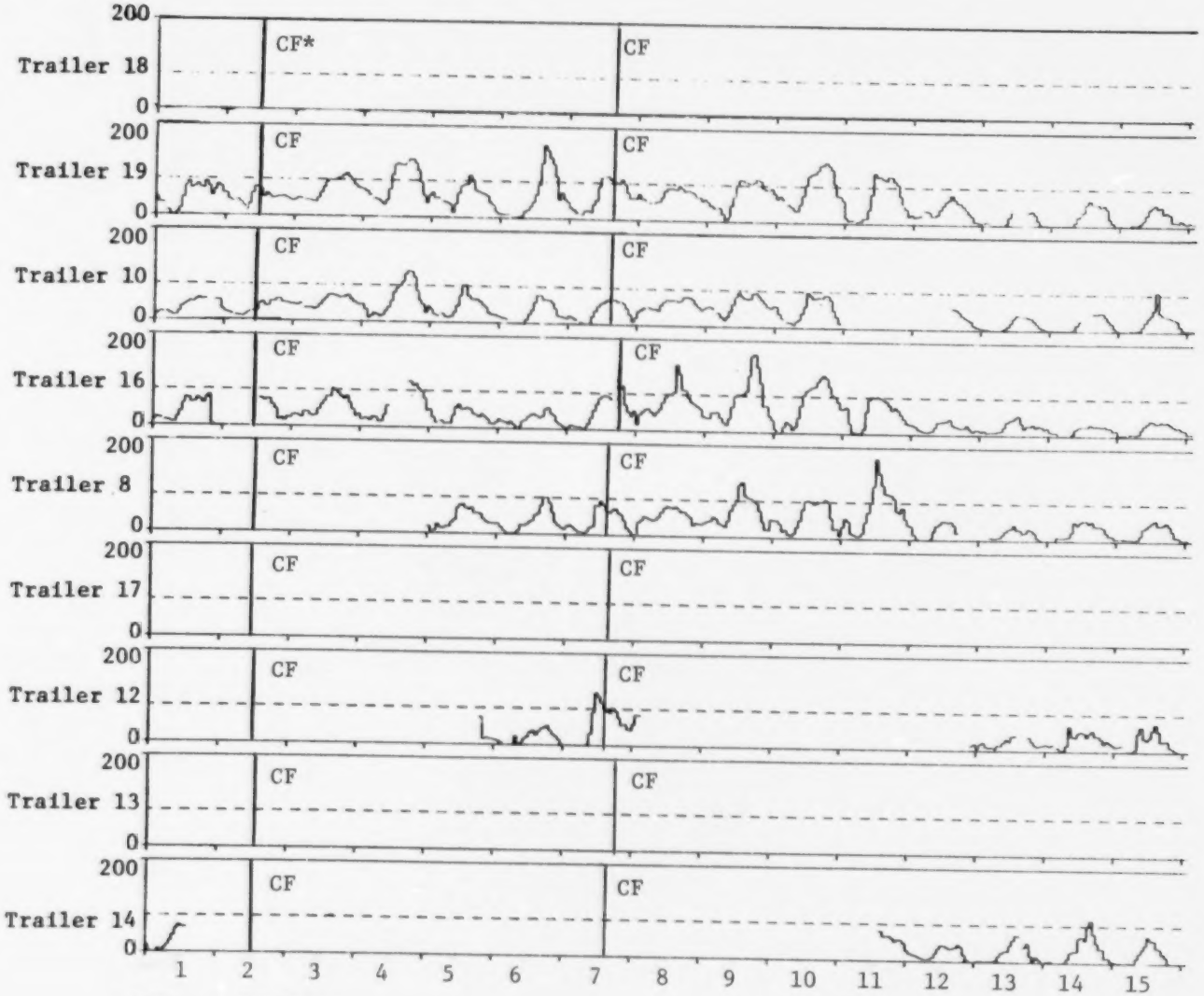
The following sections of this report are an attempt to isolate and discuss meteorological influences on the complex phenomena and interactions which determined the ambient concentrations of ozone measured at the various sites during the study. Although the scope of this paper does not include an investigation of the relationships between ozone and urban/industrial emissions, it must be kept in mind that reactions involving ozone and ozone precursors and scavengers play a major role in determining ozone trends.

Primary emphasis in the following sections will be on the relationships of ozone to the following meteorological parameters or phenomena: cold frontal passages, solar radiation, temperature, winds, precipitation, and the configuration of synoptic pressure systems. There will also be some discussion of ozone-dew point relationships.

6.1 Cold Frontal Passages

Cold frontal passages occurred in southern Louisiana on August 2nd, August 7th, late on September 9th through early on September 10th, September 21st, September 28th, October 5th, and October 16th. The approximate times of frontal passages, ± (1-3) hours, are marked on the ozone curves in Figure 6-1. The frontal passage times are marked "CF."

The change in peak ozone concentration and total area under the ozone curve from the twenty-four hours preceding the cold frontal passages to the twenty-four hours following frontal passages was investigated. The results are presented in Table 6-1. Regionwide peak concentration decreases were observed (considering trailers for which ozone data were available) for



*CF = cold front

Figure 6-1. Cold Frontal Passages at the Trailer Monitoring Sites August 1-15, 1976

(Continued)

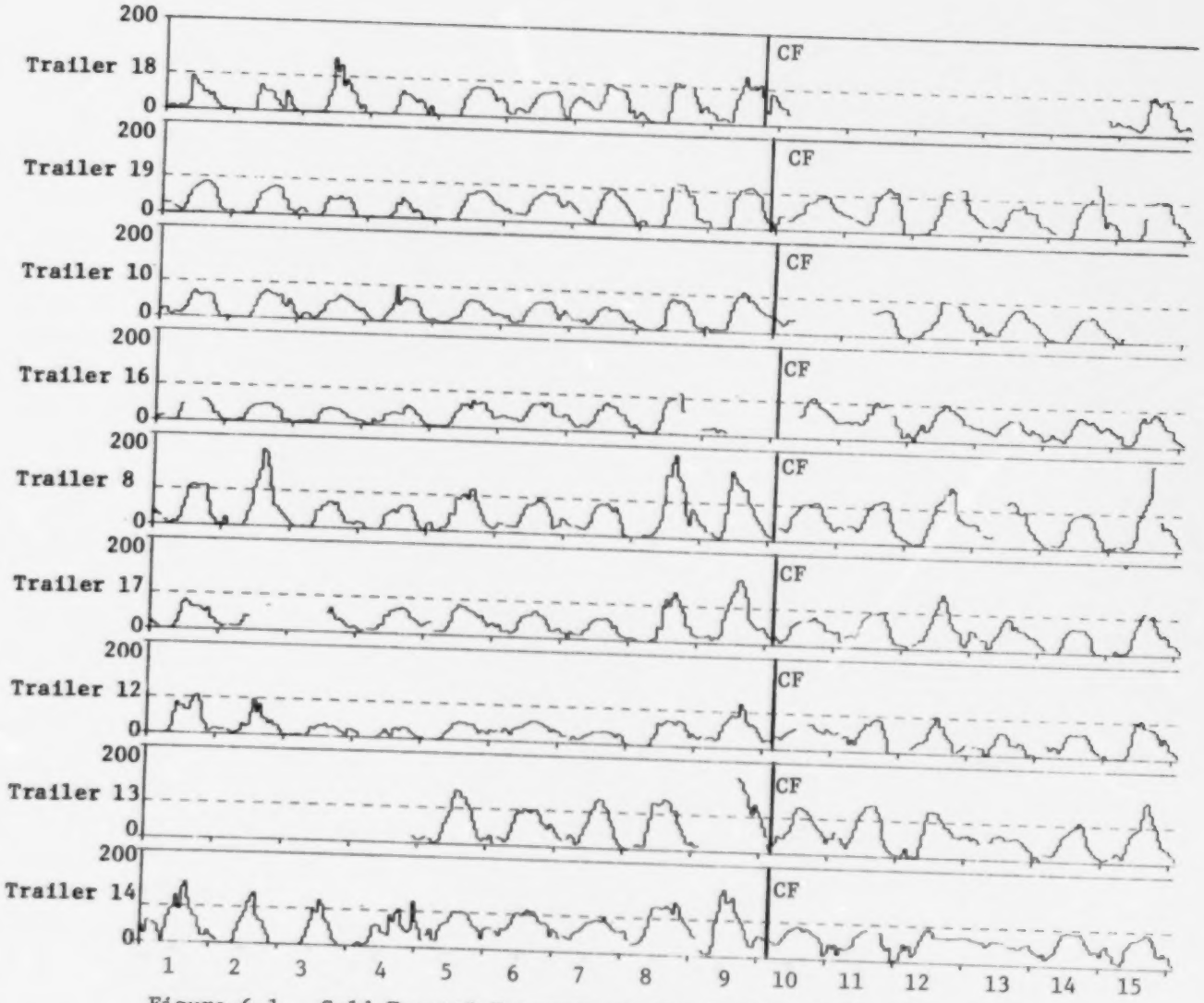


Figure 6-1. Cold Frontal Passages at the Trailer Monitoring Sites September 1-15, 1976

(Continued)

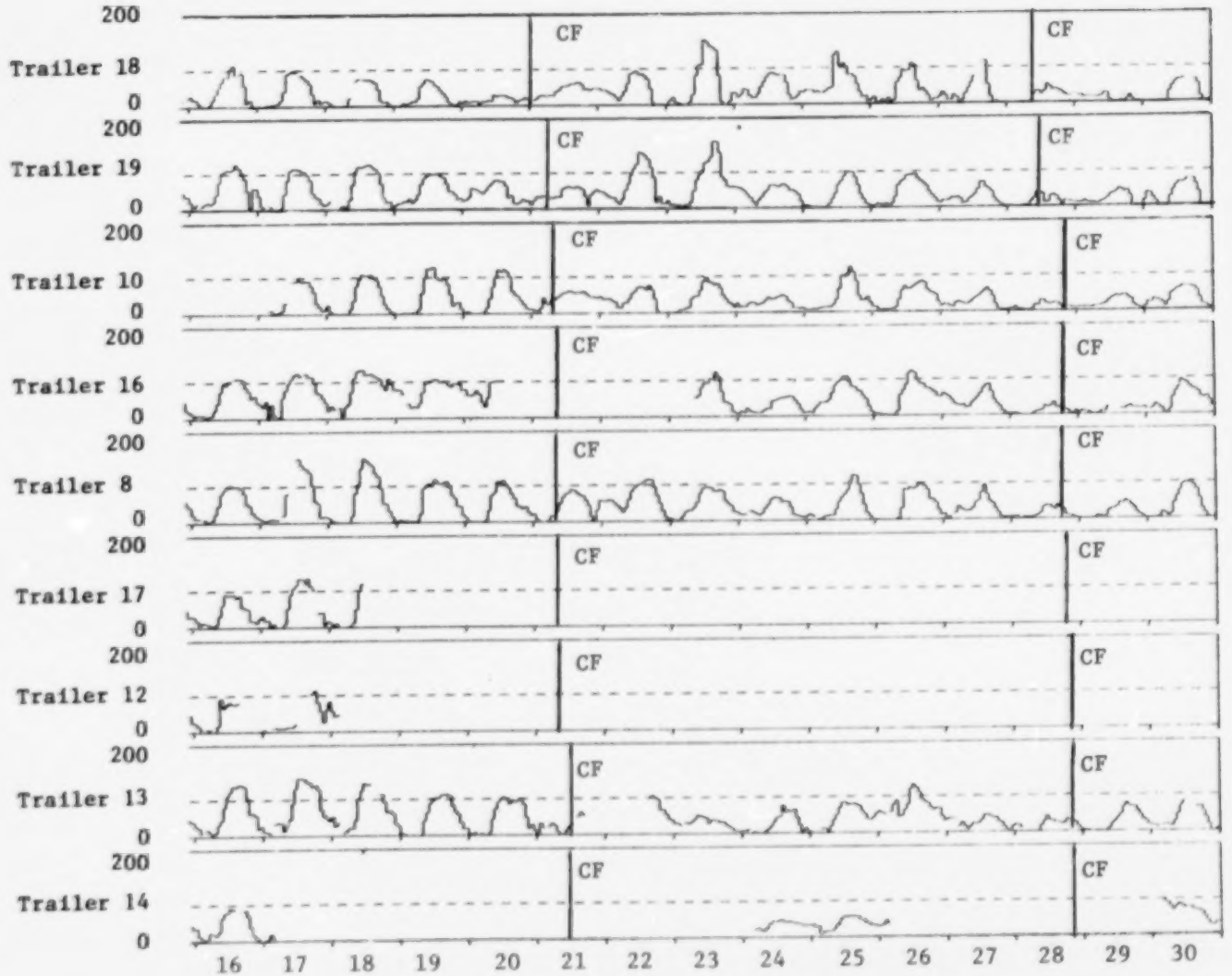


Figure 6-1. Cold Frontal Passages at the Trailer Monitoring Sites September 16-30, 1976

(Continued)

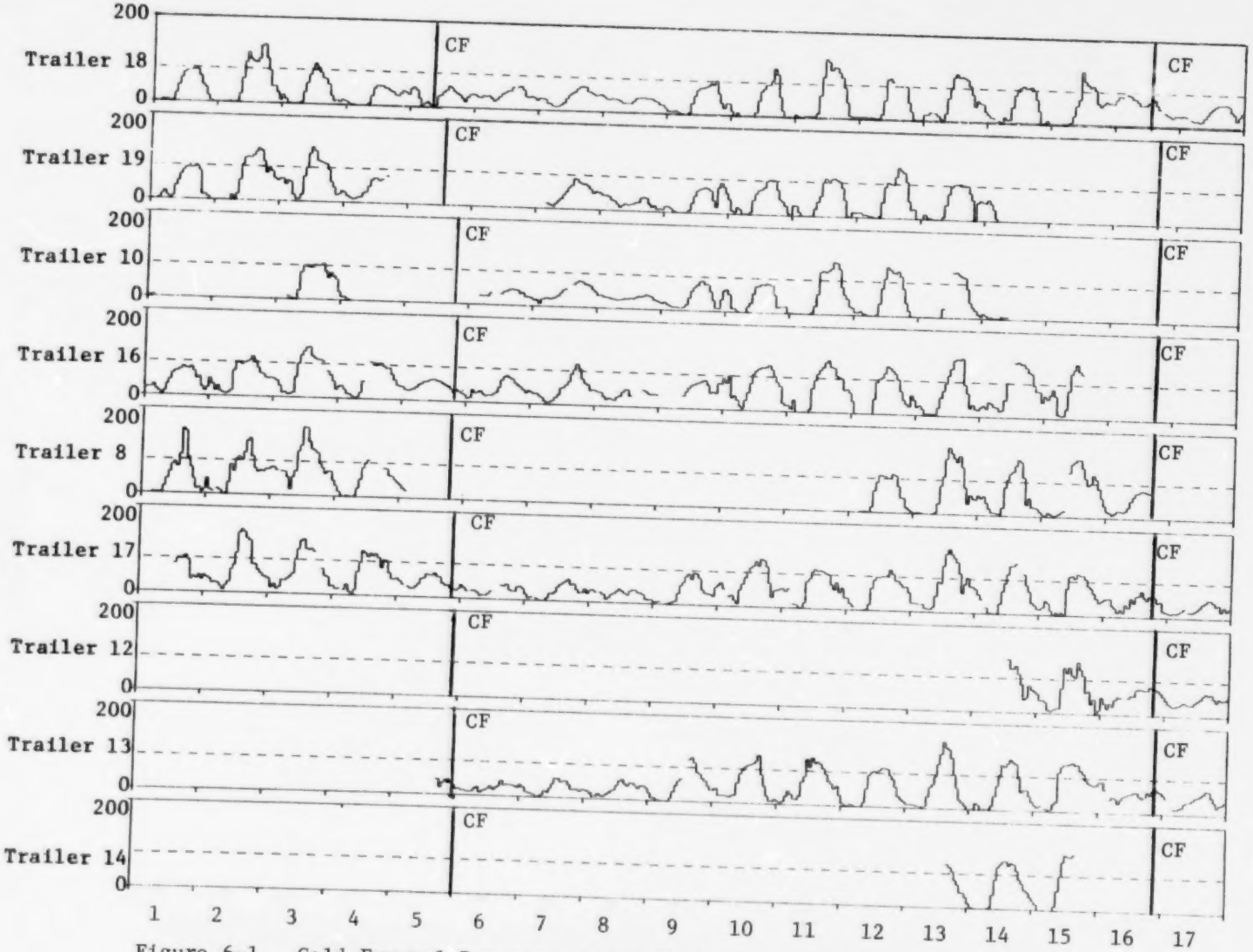


Figure 6-1. Cold Frontal Passages at the Trailer Monitoring Sites October 1-17, 1976

TABLE 6-1. Changes in Peak Ozone Concentration and Total Area Under the Ozone Curve from the Twenty-Four Hours Preceding Frontal Passage to Twenty-Four Hours Following Frontal Passage

Date of Frontal Passage	Number of Trailers with O_3 Data	Number of Trailers with Significant Peak Concentration Decrease	Number of Trailers with Significant Peak Concentration Increase	Number of Trailers with No Significant Change in Peak Concentration	Number of Trailers with Significant Decrease in Total Area Under the Curve	Number of Trailers with Significant Increase in Total Area Under the Curve	Number of Trailers with No Significant Change in Total Area Under Curve
August 2	2	0	0	2	0	0	2
August 7	4	2	1	1	0	3	1
September 9-10	6	6	0	0	5	0	1
September 21	4	3	1	0	1	1	2
September 28	6	2	3	1	1	3	2
October 5	3	1	1	1	1	0	2
October 16	4	4	0	0	3	0	1

the September 9-10th and October 16th frontal passages. For both of these frontal passages, total area under the curve decreased at all but one trailer, where no significant change occurred. However, as Table 6-1 indicates for the other frontal passages, a significant number of trailers showed increases or no significant change in peak ozone concentration and total area under the curve. Therefore, from the available ozone data, no conclusions regarding the relationship of frontal passages to peak ozone concentration and total area under the ozone curve can be made. It should be noted that the difficulty in establishing relationships between ozone concentrations and frontal passages for the available ozone data is probably due in large part to the lack of a number of really strong cold fronts, and also to the fact that weather conditions (sky cover and precipitation) were, for most frontal passages during the study period, different during the period prior to frontal passage than during the period following frontal passage. An interesting study would be to investigate ozone-frontal passage relationships for a large number of strong cold fronts. In such a study, fronts would be categorized into types; e.g., dry fronts and wet fronts. It would be desirable to concentrate on cases where sky and precipitation conditions were similar during the periods preceding and following frontal passage.

It is interesting to note that, in a significant number of cases, ozone concentrations during the first (and sometimes second) nocturnal period following frontal passage were higher than typically observed in the ozone data collected during the three-month monitoring period. A good example of this phenomenon is the character of the ozone curves associated with the frontal passage on September 9th and 10th. Ozone concentrations were higher than usual late on the 9th or early on the 10th at Trailers 018, 019, 010, 008, 012, 013, and 014 (no data were available for Trailer 016). During the following night,

ozone concentrations were higher than usual at Trailers 019, 016, 008, 017, 012, 013, and 014 (no data were available for Trailers 018 and 010).

The smaller than normal nighttime decreases in ozone from daytime accumulations were probably due at least in part to a relative lack of ozone scavengers following frontal passages. Increased winds following the frontal passages probably prevented the scavengers from accumulating to the degree that they would under light wind conditions.

In summary, the data suggest that cold frontal passages tend to be conducive to higher than usual nighttime ozone levels. However, the available data do not show any definite relationships between frontal passages and changes in peak ozone concentration and total area under the ozone curve from the twenty-four hours preceding to the twenty-four hours following frontal passage. Further investigation, utilizing a much larger set of data, is required to determine these relationships.

6.2 Solar Radiation

There should be no disagreement that solar radiation is a critical factor in ozone production. The diurnal variation of ozone is largely due to the diurnal variation in solar radiation and would not occur in the absence of a dirunal cycle in radiation intensity.

Regional ozone and meteorological data collected during the study period indicate that high solar radiation levels were conducive to high ozone concentrations, while low solar radiation levels were conducive to low ozone concentrations. It should be noted, however, that low ozone concentrations did occur on some high solar radiation days.

6.3 Temperature

Karl and DeMarrais[2] noted that Alley and Ripperton have shown in laboratory tests that ozone production is temperature dependent. Karl and DeMarrais also discussed meteorological reasons for the positive correlation of ozone concentration and the daily maximum temperature. In the current study, maximum temperatures were limited in variability except following the two strong cold frontal passages during October.

Yap and Chung[3] found that relatively low ozone concentrations prevail during periods of significantly reduced temperatures, but that high temperatures do not guarantee high ozone concentrations. An examination of concurrent values of temperature and ozone during this study support the findings of Yap and Chung.[3] The significantly lower temperatures resulting from the frontal passages in October appeared to be associated with relatively low ozone concentrations. However, high temperatures observed during the study period were not necessarily associated with high ozone concentrations.

6.4 Winds

In the construction of Table 5-1, winds were considered "reasonably persistent" if they blew from within a sector of ninety degrees. As Table 5-1 shows, winds were reasonably persistent over the region on less than half of the days during the three-month monitoring period. Periods of regionwide high ozone were, in most cases, accompanied by winds that were not reasonably persistent. However, days without reasonably persistent winds were frequently not days of high ozone concentration. Additional discussion of the statistical relationships between wind direction and pollutant concentrations is contained in the basic report on this program.

The relationship between ozone and wind speed was investigated. First, a tally was made of the number of days during the three-month monitoring period on which wind speeds were relatively light (averaged less than 8 mph) and relatively strong (averaged 8 mph or greater). A day was considered only if ozone data were available for at least four of the nine monitoring trailers. Next, the number of days on which ozone at some time was greater than or equal to 80 parts per billion at at least four trailers was tallied for each category. The same procedure was followed for days on which there were not at least four trailers recording ozone levels of 80 parts per billion or greater. The results are presented in Tables 6-2 and 6-3.

Table 6-2 indicates that high ozone occurred on 47 percent of the days with relatively light winds and on only 23 percent of the days with relatively strong winds. Table 6-3 shows that low ozone occurred on 53 percent of the days with relatively light winds and on 77 percent of the days with relatively strong winds. These results indicate that, during the study period, strong winds were conducive to low ozone levels while light winds were conducive to high ozone levels. However, low ozone levels with light winds were not at all uncommon. It should be noted that, during the three-month monitoring period, most of the strong wind days were associated with cold frontal systems. It should also be mentioned that most days on which widespread thunderstorm activity occurred were light wind days. The relationships between widespread thunderstorm activity and ozone concentrations is discussed in Section 6.5 of this report.

6.5 Precipitation

In an ozone study conducted in the eastern United States, Ludwig et al[4] pointed out that precipitation inhibits

TABLE 6-2. Comparative Frequency of High Ozone – Relatively Light vs. Relatively Strong Wind Speeds

Relative Wind Speed Category	Total Number Days for Wind Speed Category	Number Days with O_3 ≥80 ppb
Light*	70	33
Strong**	13	3

TABLE 6-3. Comparative Frequency of Low Ozone – Relatively Light vs. Relatively Strong Wind Speeds

Relative Wind Speed Category	Total Number Days for Wind Speed Category	Number Days with O_3 <80 ppb
Light*	70	37
Strong**	13	10

*Average wind speed less than 8 mph.
**Average wind speed 8 mph or greater.

the buildup of ozone, probably due to such factors as "washout of ozone or its precursors and the concurrent limited sunshine and lower temperatures that are not conducive to ozone formation."

Table 5-1 and Figure 4-1 show that, during periods when thunderstorms were scattered across all of southern Louisiana, ozone concentrations generally remained relatively low. Such periods include July 17th, July 21st through 23rd, July 29th, August 5th, August 12th through 16th, August 28th, September 3rd and 4th, and October 16th. These observations support the ideas of Ludwig et al.[4]

To further test the influence of precipitation on ozone concentrations, an investigation was made of the hourly trailer monitoring data from southern Louisiana for every case during the three-month period where precipitation was indicated and ozone data was available. The purpose of the test was to compare the concentration of ozone which existed before a precipitation period with the concentration during and after the precipitation. Four cases were investigated:

Case I - Ozone concentrations greater than or equal to 80 parts per billion; daytime period.

Case II - Ozone concentrations greater than or equal to 80 parts per billion; nighttime period.

Case III - Ozone concentrations less than 80 parts per billion; daytime period.

Case IV - Ozone concentration less than 80 parts; nighttime period.

Case I

For Case I (high ozone, daytime), there were only four periods of precipitation occurring during one or more hours for which concurrent ozone data were available. The comparison between hourly ozone concentrations prior to rainfall periods and hourly concentrations during and after the rainfall periods showed that decreases occurred in hourly concentrations in three out of four of the instances. The ozone concentration increased with the fourth precipitation occurrence. Since hourly averages do not indicate whether ozone increased or decreased at the time of the precipitation occurrence, five-minute averages of ozone and precipitation were investigated to determine with more confidence what the ozone-precipitation relationships were. For the instances in which hourly ozone concentrations decreased when hourly precipitation occurred, five-minute averages indicate that ozone did decrease as rain began (the decreases were not rapid). Five-minute averages show that, during precipitation periods, ozone concentrations fluctuated somewhat (small rises and drops). It should also be mentioned that in two out of the three instances where ozone decreased during the precipitation period, the precipitation occurred so late in the day that solar radiation would have been decreasing even if no cloud cover or precipitation were present. Therefore, ozone concentrations may have decreased even if the sky were clear.

From the available data, a clear relationship between high daytime ozone and precipitation is not shown, for several reasons. First of all, there is a very limited amount of data (only four instances of precipitation and high ozone occurring concurrently). Furthermore, in one of these instances, ozone actually increased with the occurrence of precipitation. And,

as mentioned already, in three of the instances the precipitation occurred so late in the day that the normal decrease in solar radiation may have resulted in decreased ozone regardless of whether precipitation occurred.

For conclusive evidence of a relationship between high daytime ozone and precipitation, a very detailed study would be necessary. A large data set which includes periods of rainfall in the early afternoon would be required. Furthermore, details on the type of storm (squall line, isolated shower, etc.) would be necessary as well as other storm characteristics (height of storm cloud, intensity and location of electrical activity, etc.). Although from the available data there is no conclusive evidence of a relationship between precipitation and high ozone concentrations during the day, a possible relationship certainly should not be ruled out. The fact that only a few cases of high daytime ozone occurred prior to periods of precipitation may in itself suggest that days on which precipitation occurs are usually not high ozone days.

Case II

For Case II (high ozone; nighttime) only one instance of precipitation occurred. This is not surprising; high ozone would not be expected to occur often during nighttime periods. No change in ozone concentrations (on an hourly basis) occurred for the hour during which rain fell. The hourly ozone concentration decreased during the hour following the end of the precipitation. With only one occurrence of precipitation for Class II, it would be unwise to even attempt a conclusion about the effect of precipitation on high nighttime ozone.

Case III

For Case III (low ozone; daytime) there were twenty-two periods of precipitation occurring during one or more hours for which concurrent ozone data were available. A comparison of hourly ozone concentrations before and concentrations during precipitation periods showed an increase in ozone in eight instances, a decrease in eleven, and no change in three. A comparison between hourly concentrations before precipitation periods began and concentrations during the hour after the precipitation periods shows an increase in nine instances and a decrease in twelve (ozone data was not available in one instance). In almost all cases, a comparison of ozone concentrations during and after precipitation periods showed an increase or decrease if the comparison between ozone before and during precipitation periods showed an increase or decrease, respectively. Further investigation into the comparison between ozone concentrations before and concentrations during precipitation periods shows that seven out of eight of the ozone increases occurred with precipitation periods which began between 8 a.m. and 11 a.m. One instance of an ozone increase occurred with a precipitation period which began at 3 p.m. Nine out of eleven of the ozone decreases occurred with precipitation periods which began during the interval from 1 p.m. to 5 p.m. One ozone decrease occurred with a precipitation period which began at 10 a.m. while another occurred with a precipitation period which began at 11 a.m. Further investigation into the comparison between hourly ozone concentrations before and concentrations after precipitation periods shows that seven out of the nine ozone increases occurred with precipitation periods which began during the interval from 8 a.m. to 10 a.m. One ozone increase occurred with a precipitation period which began at 11 a.m., and another with a precipitation period which began at 3 p.m. Nine out of twelve ozone decreases

occurred with precipitation periods which began during the interval from 1 p.m. through 5 p.m. Two ozone decreases occurred with precipitation periods which began at 11 a.m., and one with a precipitation period which began at 10 a.m.

In summary, then, most ozone increases in association with precipitation occurred during the morning hours while most decreases occurred during the afternoon hours. A possible explanation for the morning increases is that ozone was brought down from aloft by vertical mixing resulting from the downrush of air associated with the rainfall activity. During the night, while ozone is scavenged near the ground (below the top of the nocturnal inversion), ozone levels may remain relatively high above the inversion. Vertical mixing created by the downrush of air associated with the precipitation in the morning may bring down the ozone of higher concentration, thus increasing the concentration at the ground. The washout of ozone and its precursors, and the effect of limited solar radiation and cooler temperatures may be overridden by the downrush of air of higher ozone concentrations. Although measurements of ozone aloft would be necessary for further investigation of this phenomenon, the data do support the hypothesis. An important point is that the continued increase in ozone concentrations after morning precipitation periods end may in many cases be due at least in part to increasing solar radiation as cloud cover diminishes.

The tendency for low ozone concentrations to decrease with afternoon precipitation may be due to the washout of ozone and its precursors, limited solar radiation, relatively cool temperatures, or vertical mixing associated with the downrush of air which is cleaner than the air at the surface (measurements of ozone aloft would be necessary for further investigation of this possibility). Some or all of these factors may influence the ozone concentrations. In about a third of the instances of

decreasing ozone with precipitation, the precipitation period began so late in the afternoon that the decrease in ozone may have been due in part to the normal decrease in solar radiation late in the afternoon.

Case IV

For Case IV (low ozone, nighttime), there were nine periods of precipitation occurring during one or more hours for which concurrent ozone data were available. A comparison of hourly ozone concentrations before and concentrations during precipitation periods showed an increase in ozone in six instances (in five instances, the increase was significant), a decrease in two (one of which was significant) and no change in one instance. A comparison of hourly ozone concentrations before and after precipitation periods showed an increase in ozone in four instances, and a decrease in five. In each instance, the ozone concentration for the hour after the precipitation ended was lower than the concentration during the precipitation period.

The limited amount of data for Case IV makes a clear relationship between low nighttime ozone and precipitation difficult to discern. It might be suggested that, for cases where ozone increased significantly with precipitation, ozone of higher concentration may have been mixed down from a layer above the nocturnal inversion into the layer close to the ground where ozone levels were low due to scavenging effects. For cases where only a small increase or decrease occurred, or where no change occurred, a radiation inversion may not have been present prior to the rainfall, such that the layer close to the ground contained ozone of a similar concentration to that in higher layers (a very detailed investigation would be necessary to confirm this hypothesis). For cases where a significant decrease occurred, vertical mixing

due to a downrush of air may have brought down ozone of a lower concentration from aloft. Again, a detailed investigation would be necessary to determine the reasons for the behavior of ozone concentrations as the precipitation occurred.

The following conclusions result from the investigation into the relationship between ozone and precipitation:

- Periods of widespread precipitation over the region during the summer and early fall appear to be associated with relatively low ozone levels over the region.

- In general, the data support a conclusion that precipitation has a marginal effect on the diurnal pattern commonly found in studying ozone concentrations. This is supported by the following observations:

  - During the monitoring periods, when precipitation occurred during afternoon periods of low ozone levels, ozone levels generally decreased.

  - When precipitation occurred during morning periods of low ozone (after sunrise), ozone levels generally increased.

  - Low nighttime ozone levels increased with precipitation in some cases and decreased in others, possibly dependent on whether ozone levels were higher or lower in the layers aloft than in the surface layer.

6.6 Synoptic Pressure Systems

During the three-month monitoring period in southern Louisiana, there was not much variability in the configuration of the synoptic pressure systems which dominated the weather. The region was dominated by anticyclonic systems (high pressure) on the majority of days. The typical pressure system configuration was a ridge of high pressure extending into Louisiana from the northeastern or eastern United States. Such a configuration produces generally light winds; therefore, winds were light on the majority of days during the three-month period (see Table 6-1). With a ridge of high pressure extending into southern Louisiana during the summer and early fall, a variety of other meteorological conditions can occur, however. In particular, widespread thunderstorm and their associated cloudiness can occur if abundant moisture is entrained into the region or if an upper level disturbance moves over the region. But the majority of days when the region is dominated by high pressure are sunny, with either no thunderstorms or only isolated thunderstorms.

In a study of the relationship between ozone and high pressure systems, Vukovich et al[5] examined data from rural sites across the northern and eastern portions of the nation. High ozone was correlated with high pressure systems in the eastern U.S. The highest ozone was found in the central region of high pressure, where weak winds, disorganized flow, and relatively clear skies prevailed. High ozone was quite common on the back side of high pressure systems. However, the study showed that the presence of a high pressure system does not necessarily imply the existence of high ozone. As noted earlier, high pressure affected southern Louisiana during the monitoring period generally in the form of a ridge extending into the region instead of a strong high pressure system (with a well defined center) moving across the area.

For southern Louisiana, the relationship between curvature of pressure systems (anticyclonic or cyclonic) and ozone concentrations was investigated. First, a tally was made of the number of days on which the curvature was anticyclonic and the number of days on which the curvature was cyclonic. A day was considered only if ozone data were available for at least four of the nine monitoring trailers. Each curvature category was divided into days with relatively light winds (wind speed averaged less than 8 mph) and days with relatively strong winds (8 mph or greater). Next, the number of days on which the ozone was greater than or equal to 80 parts per billion at at least four trailers was tallied for each curvature and wind speed category. Finally, the percentage of days on which high ozone occurred was calculated for each curvature and wind speed category.

The same procedure was followed for days when there were not at least four out of nine trailers recording ozone levels of 80 parts per billion or greater. The results are presented in Tables 6-4 and 6-5.

Not surprisingly, there were many more days of anticyclonic curvature than cyclonic and neutral curvatures. Due to the shortage of data for cyclonic and neutral curvatures, it should not be concluded that any of the curvature categories is more conducive to high ozone than the others.

Tables 6-4 and 6-5 actually produce the same results as Tables 6-2 and 6-3 - that, during the study period, strong winds were conducive to low ozone levels while light winds were conductive to high ozone levels, although low ozone levels with light winds were not uncommon.

TABLE 6-4. Occurrence of High Ozone Levels (>80 ppb) with Various Categories of Pressure System Curvature

Curvature Category	Relative Wind Speed	Total Number Days for Category	Number Days with O_3 ≥80 ppb	Percent of Total Number Days for Category
Anticyclonic	Light*	51	22	43
Anticyclonic	Strong**	10	3	33
Cyclonic	Light	10	5	50
Cyclonic	Strong	3	0	0
Neutral	Light	9	6	67
Neutral	Strong	0	0	-

*Average wind speed less than 8 mph.
**Average wind speed 8 mph or greater.

TABLE 6-5. Occurrence of Low Ozone Levels (<80 ppb) with Various Categories of Pressure System Curvature

Curvature Category	Relative Wind Speed	Total Number Days for Category	Number Days with O_3 <80 ppb	Percent of Total Number Days for Category
Anticyclonic	Light	51	29	57
Anticyclonic	Strong	10	7	70
Cyclonic	Light	10	5	50
Cyclonic	Strong	3	3	100
Neutral	Light	9	3	33
Neutral	Strong	0	0	-

The available data, then, do not show conclusive evidence that curvature of pressure systems is important in relation to ozone levels during the summer and early fall. A much longer monitoring period, spanning many months, would be required for further investigation.

6.7 Dew Point

Daily average dew point temperatures for the three-month monitoring period were obtained from National Weather Service records. Comparison of dew point and ozone trends indicated no clear relationships for July, August, and September. However, during the month of October, the periods of low dew point associated with the strong cold frontal passages were accomplanied by low ozone levels. As discussed in earlier sections of this paper, a number of other factors associated with the cold frontal passages (stronger winds, lower temperatures, etc.) were probably influential in reducing ozone levels. Therefore, the relative effect of low dew points on ozone levels is not clear.

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